

BELLCOMM, INC.

955 L'ENFANT PLAZA NORTH, S.W.

WASHINGTON, D. C. 20024

SUBJECT: Payload Capability and Launch
Windows for AAP Missions at 35°
Inclination - Case 610

DATE: December 20, 1968

FROM: W. L. Austin
I. Hirsch
K. E. Martersteck

ABSTRACT

Analyses of AAP rendezvous missions show that launch windows are much narrower and launch opportunities fewer with the new 35° inclination orbit. Data from precision simulations are presented showing how payload varies with launch time during the launch window for both LM/ATM and CM/SM launches.

In the case of the LM/ATM, it will not be possible to have a daily launch opportunity because the LM/ATM can only be launched when specific conditions on both the position of the Workshop orbit plane and the position of the Workshop in its orbit are simultaneously satisfied. This dual requirement on launch time will in general necessitate launching the LM/ATM with a component of velocity toward the target plane and yaw steering the launch vehicle to insert the LM/ATM into the desired plane, causing a loss of payload capability depending on the amount of yawing required.

The CM/SM launches, which must be made along southerly azimuths for greater abort safety because an SPS insertion burn is planned, are less severely constrained. The CM/SM can loiter for several revolutions in a parking orbit until the phasing condition for rendezvous is satisfied. In order to reduce the phasing time it may be desirable to accept a loss in CM/SM payload in order to launch when the in-phase condition is satisfied. In such cases flight along a non-optimum azimuth and yaw steering into the target orbit plane result.

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MEMORANDUM FOR FILEI. INTRODUCTION

The inclination of the AAP Orbital Workshop has been changed from 29° to 35°. Most recently the use of the Service Propulsion System of the Service Module to achieve orbit (SPS insertion) has been baselined for all AAP CM/SM flights. The higher inclination incurs a payload penalty on all launches and makes rendezvous appreciably more difficult. The SPS insertion offers substantial payload capability improvement on the manned launches but the scheme also provokes special crew and range safety considerations which further limit the rendezvous options for these flights.

In this memorandum we shall explore these topics and present the results of computer simulations that express these effects quantitatively.

II. LAUNCH WINDOW CONSIDERATIONS

A 35° inclination orbit crosses the latitude of Cape Kennedy twice, northbound and southbound. Rockets can be launched into this plane most easily and efficiently on launch azimuths of 67° or 112° respectively with no yaw steering required. Because all the acceleration is in the same plane, in these two cases the payload capability is maximum. Flying into a specific inertial orbit plane requires a launch at the exact instant in the day when the earth's rotation brings the launch site to the target orbit plane at one point or the other. This instant is called the center of a launch window, because the target orbit plane can also be achieved from a somewhat earlier or later launch time, but only by flying into the plane with a deflected launch azimuth and a subsequent yaw turn during ascent.

For example, if it is desired to launch a little earlier than the optimum northbound launch opportunity, the rocket will start from a point too far to the west, or left of the orbit plane when looking down range. The launch azimuth must be deflected to the right toward the desired plane, and then a yaw turn to the left is required to bring the flight path tangent to the plane at cutoff. A specific combination of yaw rate and launch azimuth deflection is required to put both position and velocity in the

desired plane at cutoff. The magnitude of these adjustments are almost linearly proportional to the launch time deviation from the optimum or center of the launch window.

These yaw turning maneuvers incur a payload loss. Figure 1 shows the exact variation in payload capability, launch azimuth and yaw rate for the LM/ATM flight as the launch occurs before or after the northerly optimum. The data were obtained from precision powered flight simulations that were targeted to the desired conditions using BCMASP, our standard simulator program (References 1 and 2). In the simulations the yaw maneuvers were restricted to the second stage operation to preserve a small angle of attack throughout first stage burn when aerodynamic forces are large. A yaw angle rotation was introduced 30 seconds after S-IVB ignition when closed-loop guidance would begin and a constant yaw rate was maintained thereafter until S-IVB cutoff. With three parameters (launch azimuth, yaw angle, and yaw rate) available to control out-of-plane position and velocity, it was possible to choose a combination that also optimized payload. It was noted that the payload optimization resulted in values of yaw angle very close to zero. However, insufficient data were available to determine whether zero yaw angle is a sufficient criterion for optimizing payload.

The size of the launch window depends on how much payload can be sacrificed. For 1000 lbs one can buy about +20 minutes in the LM/ATM window. The associated launch azimuth varies from 59° to 75° and the yaw rate from $-.06$ to $+.06$ deg/sec. Similar curves for a southerly LM/ATM launch could be computed but we have not done so. They should be nearly identical to these except for a reversal of symmetry and launch azimuths centered on 112° .

III. SELECTION OF THE LAUNCH CORRIDOR

The track of the instantaneous impact point (IIP) during launch for the optimum ascent trajectory is determined by the launch azimuth of 67° or 112° . The northern course goes well out into the Atlantic with no islands nearby, but swings south across the widest part of Africa in the latter phases of boost. On the southern course, the IIP passes just north of the Bahama and the Leeward Islands, into the South Atlantic between South America and Africa, and crosses the southern tip of Africa very quickly just before passing into orbit.

For launches off the optimum, the deflected launch azimuth will deflect the first stage IIP correspondingly. However the subsequent yaw turn brings the IIP path back parallel to the optimum path. The deviation is bounded by the ground track of the target orbit for the earliest and latest possible launch times. Assuming a launch window of +20 minutes, the ground track shifts +300 nm in the east-west direction. This projects at the equator into a cross-track deviation of only about ± 170 nm.

It is likely that the LM/ATM launch will be restricted to the northern corridor and the manned CM/SM launches to the southern corridor. The northern corridor is preferred for the LM/ATM because good tracking coverage of the unmanned rendezvous is assured. In addition the entire launch window can be used without having the IIP track encroach on any island or land mass. For the southerly sector, the optimum trajectory passes so close to some islands that any deflection to the right (late launch) would be questionable. Thus only half of the launch window is actually available.

During the SPS insertion burn of the manned CM/SM launches, any abort procedure which would normally require operation of the SPS cannot be used. In other words, with the exception of the relatively limited RCS capability, there is no backup propulsion system to alter the CM/SM trajectory should the SPS prematurely shut down. As a result, should an abort occur while the IIP is over Africa, a land landing potentially hazardous to the crew would be virtually unavoidable. According to MSC sources, the RCS could move the IIP by about three seconds so that, if the IIP at the time of abort were within about three seconds of a coastline, use of the RCS could make a water landing possible. By restricting the CM/SM launches to southerly azimuths, the land-landing problem is significantly reduced, if not eliminated, for the IIP dwell time over Africa will be only a few seconds' duration compared with times of a minute or more for northerly launches. As will be discussed below, the reduced launch window concomitant with southerly launches is acceptable for the CM/SM.

IV. LAUNCH IMPLICATIONS OF RENDEZVOUS PHASING

The rendezvous situations faced by the CM/SM and the unmanned LM/ATM are somewhat different. The LM/ATM has very limited propulsion capability: two shipsets of RCS propellant only. All of this propellant is required for phasing maneuvers to correct launch vehicle down-range insertion dispersions and for the terminal phase rendezvous maneuvers, station keeping and docking. No propellant is available to correct other major position or velocity errors. Furthermore, because LM/ATM systems constraints require that the LM/ATM be docked to the Workshop and the ATM solar arrays be deployed soon after launch, extensive in-orbit phasing is precluded. Therefore, in order that the rendezvous may be promptly effected with minimum propellant expenditure, the LM/ATM must be inserted with precision in the Orbital Workshop orbit plane at a carefully selected position with respect to the Workshop. This means that at the instant of the LM/ATM launch, the Workshop must be in a very specific spot in its orbit so that at the time of LM/ATM orbit insertion the desired relative position between the spacecraft can be realized. This requirement is called the in-phase condition for launch or launch pane.

A launch opportunity exists when the time of a launch pane occurs sufficiently near the center of the launch window that the payload capability for a launch at that time will satisfy the mission requirement. The determination of acceptable launch opportunities must be the subject of a separate analysis. However, the Mission Planning and Analysis Division of MSC has produced some preliminary data on the launch panes which were presented at the AAP Guidance, Performance and Dynamics Subpanel meeting of October 23, 1968. In Figure 2, the MSC data (from Chart MDAD 4399v) are shown fitted to the launch-window curve of Figure 1. Figure 2 indicates that there exist sequences of days when a launch opportunity occurs about every third day, depending on how much payload capability is sacrificed. It appears that if about a 1000 lb reduction in maximum payload is accepted, a launch opportunity will exist at least every third day. Furthermore, it is apparent that enormous payload capability must be surrendered to ensure a daily launch opportunity.

The SM has sufficient propulsive capability, primarily in the SPS, to raise itself from the low-altitude insertion orbit to the higher-altitude Workshop orbit. The timing and magnitude of the maneuvers can be flexibly varied to achieve any desired phase shift between the vehicles. For example, if the CM/SM remains in a parking orbit 80 nm below the Workshop for about two days (30 revolutions), the phase angle will shift through a full 360°. If this much time could be allocated, all restrictions on launch time due to phasing would be eliminated. This extreme flexibility must be considered against the desire to complete rendezvous expeditiously so that Workshop activities may begin.

V. AAP LAUNCH SIMULATIONS

In the simulations described below, engine performance and stage weight data were obtained from References 3-6. Launch Vehicle 209 data were used for CM/SM runs while Vehicle 210 data were used for the LM/ATM. In all cases a flight performance reserve of 1500 lbs was carried in the S-IVB. Although the actual performance will vary somewhat from one vehicle to another, the conclusions based on the performance trade-offs discussed here remain valid regardless of which vehicle is assigned to a particular mission.

A. LM/ATM Launch

Assuming a nominal atmospheric density, at the time of the AAP-4 launch the Orbital Workshop will be in a circular orbit with an altitude of about 198 nm. According to Reference 7, the LM/ATM should be inserted 12 nm below the Workshop into an orbit with apogee 10 nm above the Workshop. Therefore, the LM/ATM was targeted for a 186 x 208 nm orbit coplanar with the Workshop orbit.

The data of Figure 1 were generated in the following manner. First, a family of trajectories were run with constant launch azimuth and targeted to 35° inclination and specified descending node angles by iterating on yaw angle and yaw rate. Payload vs descending node was plotted for each azimuth. By cross-plotting, the maximum payload optimum launch azimuth, yaw angle, and yaw rate for various values of descending node were then determined and the data fitted with curves. For computational convenience descending node (measured with respect to the longitude of the launch site at the time of launch) rather than time in the launch window was chosen as the independent variable. However, the time and descending node values are equivalent, being related simply by the earth's rotation rate minus the nodal regression rate. The attached figures show both the descending node and the corresponding time in the window.

B. CM/SM Launch

The CM/SM is inserted at perigee into an 81×120 nm parking orbit by the SPS which is burned to orbit insertion after S-IVB cutoff. A brief study was made to determine the optimum amount of SPS propellant to be loaded for this burn to maximize total vehicle weight at cutoff. Two cases were investigated: launch azimuth = 112° , descending node = 52° , (the center of the CM/SM launch window); and launch azimuth = 101° , descending node = 56.5° (about 17 minutes before the window center). As shown in Figure 3, the payload is relatively insensitive to the SPS propellant loading. The optimum value, 15000 lbs, was used in all of the subsequent simulations.

The payload capability, optimum azimuth and yaw rate data for the CM/SM launch window, shown in Figure 4, were generated by the same technique discussed above for the LM/ATM. As before, the powered flight was targeted so that the vehicle would be in the target plane at S-IVB cutoff. The CM/SM was then rotated so that the SPS thrust was directed only in the target plane; no yawing was done by the CM/SM during the SPS insertion burn. An eight-second delay was assumed between S-IVB cutoff and SPS ignition. No flight performance reserve allowance was deducted from the CM/SM payload weight.

As pointed out above, the CM/SM launches will probably be restricted to the "early half" of the launch window, i.e., azimuths $< 112^\circ$, in order to avoid jeopardizing the Bahama Islands. If desired, it is possible to extend the usable portion of the window beyond the center by holding the launch azimuth at 112° and using the yaw angle and yaw rate to null the out-of-plane position and velocity at cutoff. The greater payload penalty for this procedure is evident from Figure 4. Furthermore, the applicability of this procedure is limited for, as seen in Figures 5 and 6, even though the Bahamas are cleared, the yaw turn soon causes the IIP to cross the Leeward Islands.

Finally, it is noteworthy that, should the launch azimuths be restricted for range safety reasons further to the north than 112° , CM/SM launches could still be accomplished with relatively little loss in payload capability. For example, launching along an azimuth of 108° , the southern limit of the Apollo corridor, would result in a payload loss of only about 50 lbs from the maximum achievable with a launch at the center of the window along an azimuth of 112° .

VI. SUMMARY

The change in the baseline inclination of the Orbital Workshop orbit to 35° has a profound effect on the launch opportunities for the LM/ATM and CM/SM's. In general, rendezvous requirements on spacecraft insertion conditions will make necessary the use of launch-vehicle yaw steering with subsequent loss in payload capability in proportion to the amount of yawing required.

Because both plane and phase constraints must be simultaneously satisfied at the time of the LM/ATM launch, there will be relatively few opportunities to launch the LM/ATM unless some payload penalty is accepted. Because the CM/SM has in-orbit phasing capability, its launch will be constrained primarily by the in-plane condition. However, it still may be desirable to do some yaw turning during the boost of the CM/SM so that a minimum amount of on-orbit mission time is spent on phasing.

VII. ACKNOWLEDGEMENT

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Attachments

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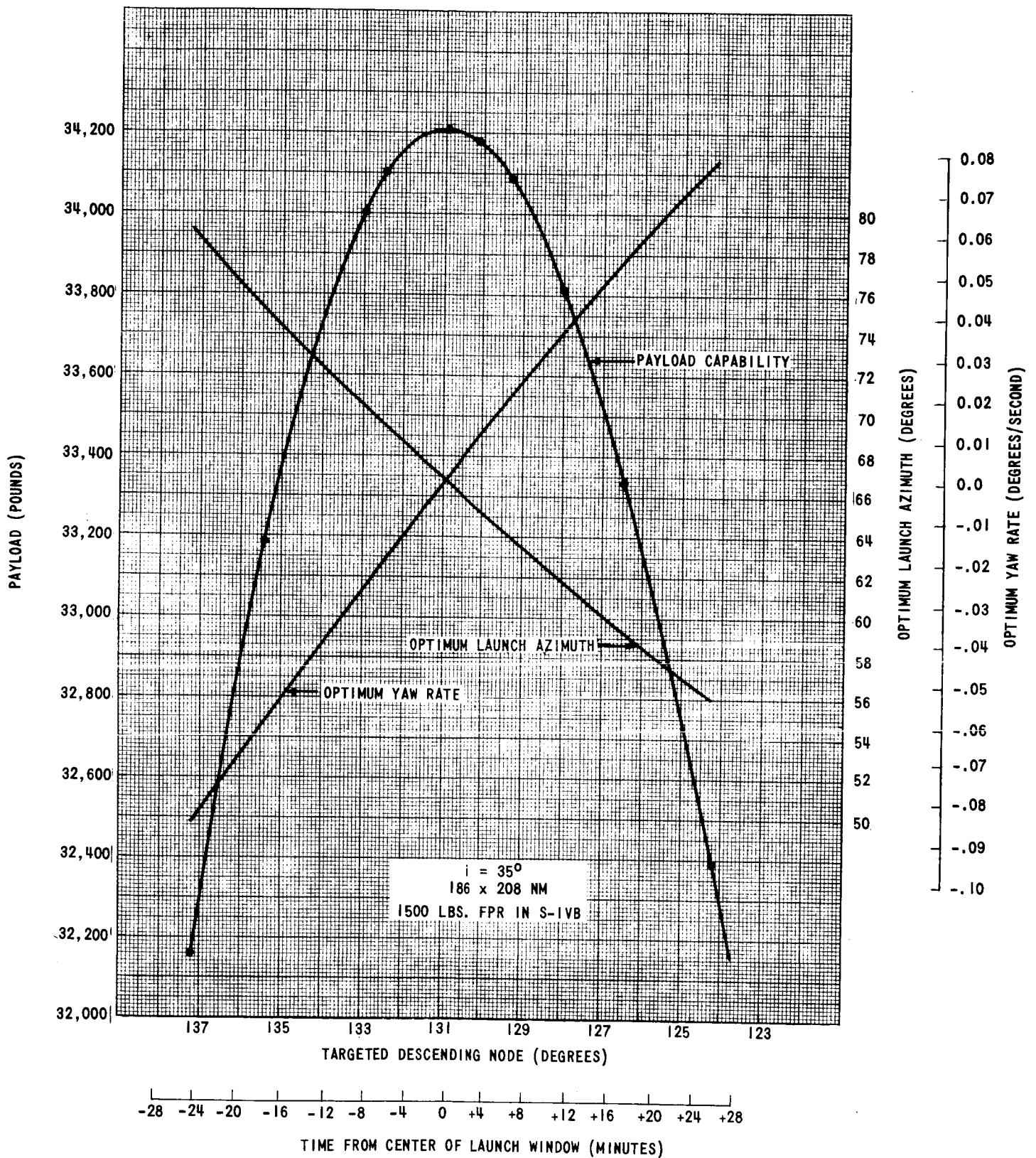


FIGURE 1 - PAYLOAD CAPABILITY, OPTIMUM LAUNCH AZIMUTH AND YAW RATE FOR LM/ATM NORTHERLY LAUNCHES

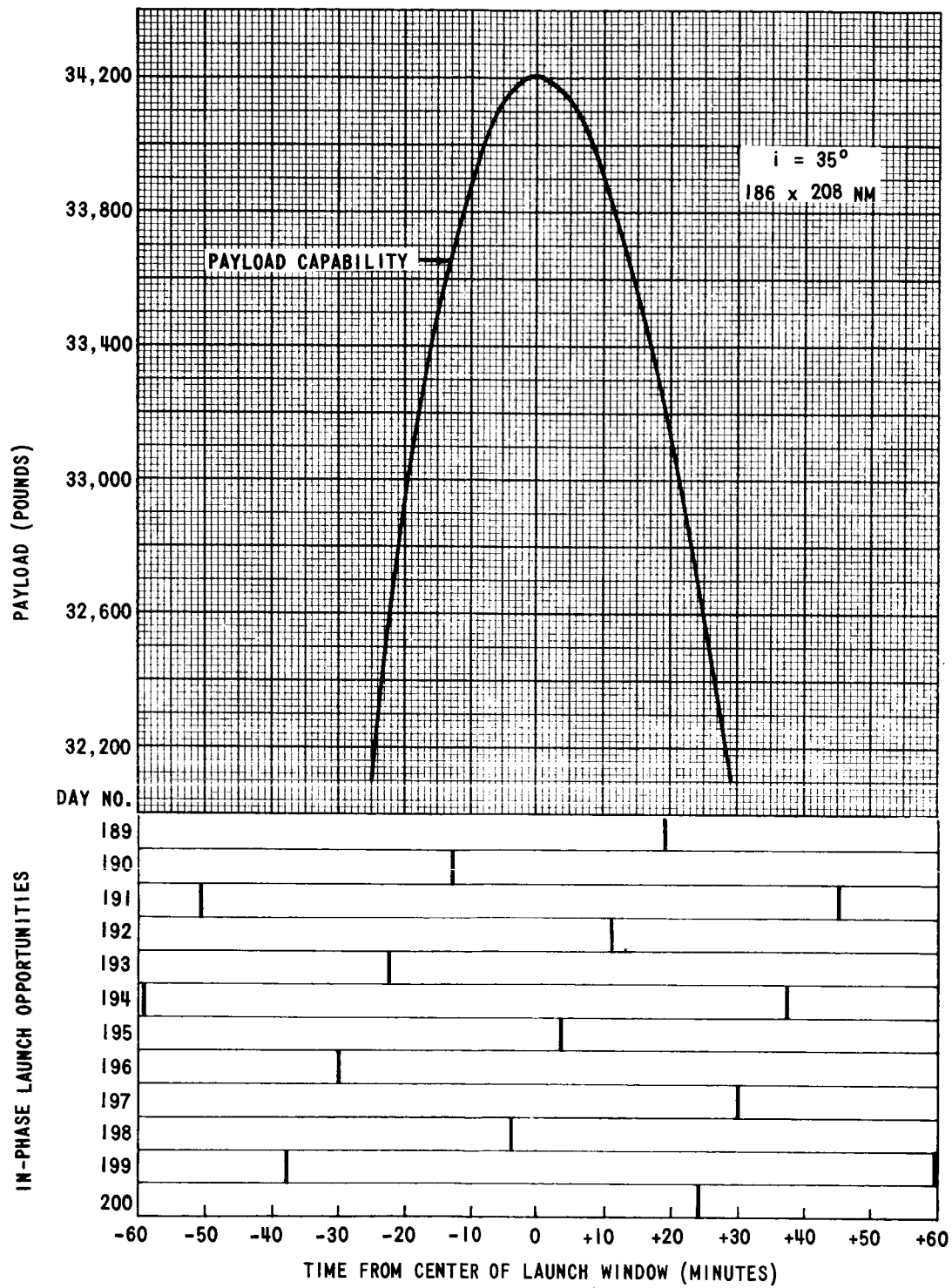


FIGURE 2 - LM/ATM NORTHERLY LAUNCH OPPORTUNITIES

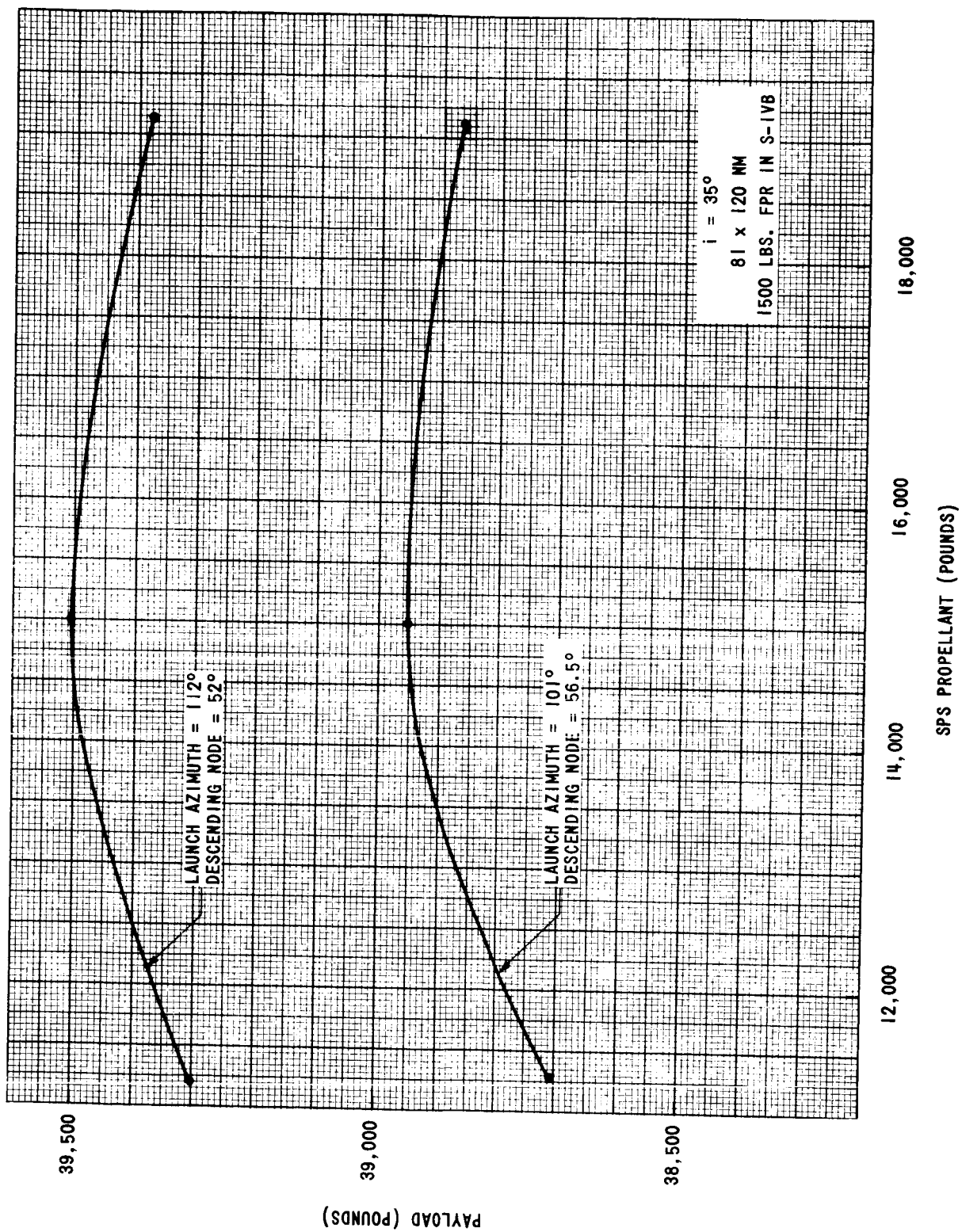


FIGURE 3 - VARIATION IN PAYLOAD WITH SPS PROPELLANT LOADED FOR SPS INSERTION

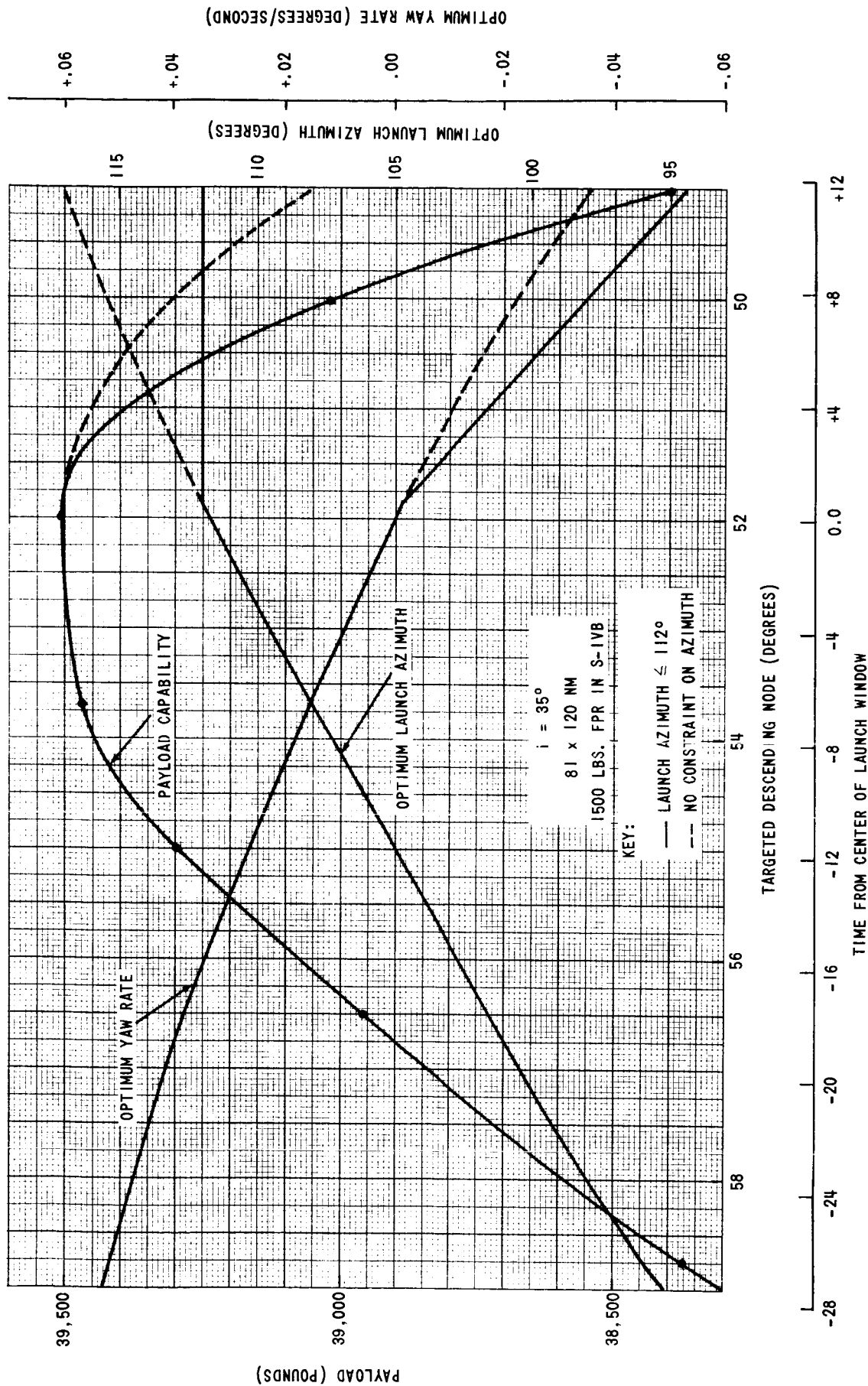


FIGURE 4 - PAYLOAD CAPABILITY, OPTIMUM LAUNCH AZIMUTH AND YAW RATE FOR CM/SM LAUNCH AND SPS INSERTION ALONG SOUTHERLY AZIMUTHS

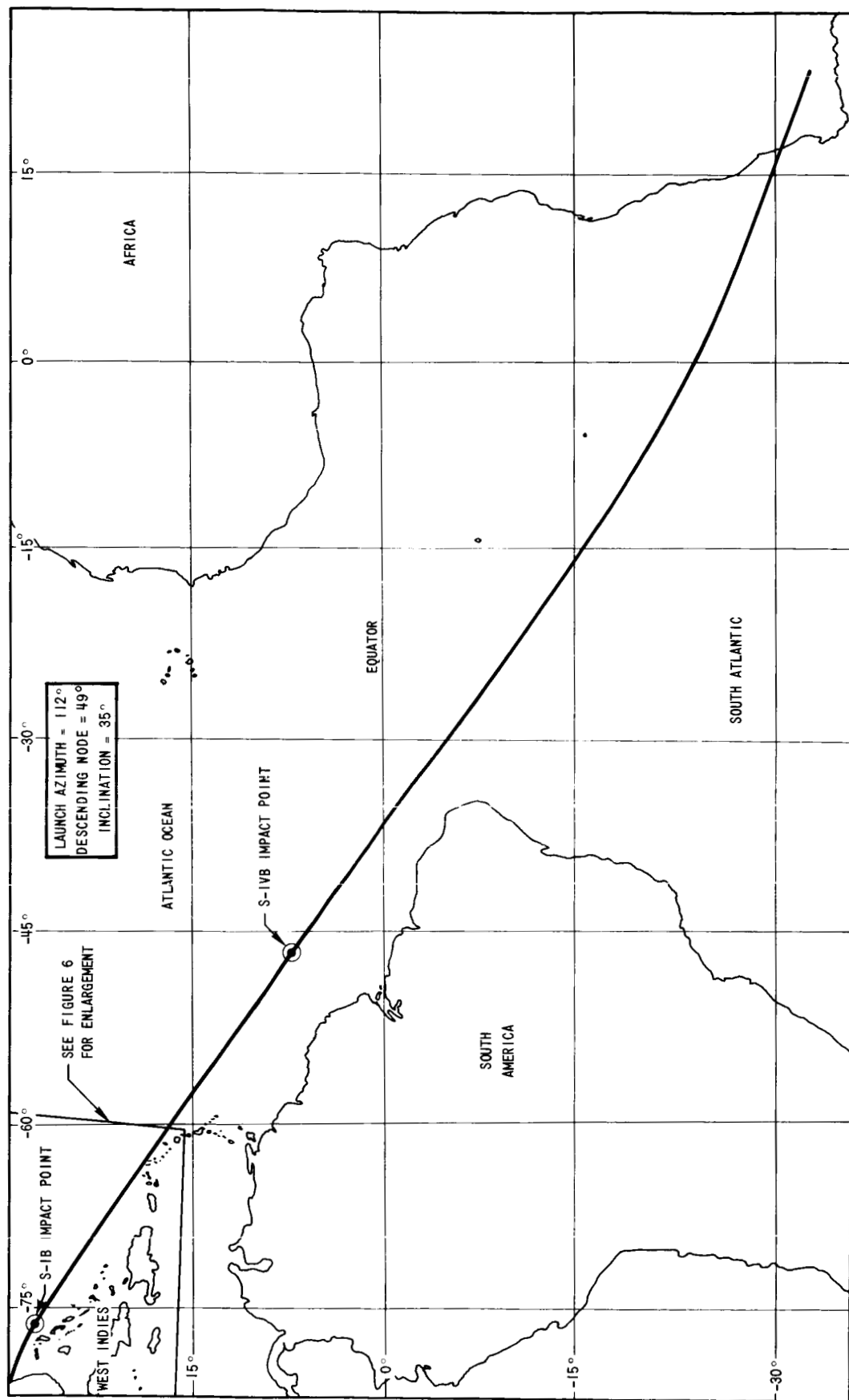


FIGURE 5 - INSTANTANEOUS IMPACT POINT (IIP) PLOT FOR SOUTHERLY LAUNCH OF CM/SM

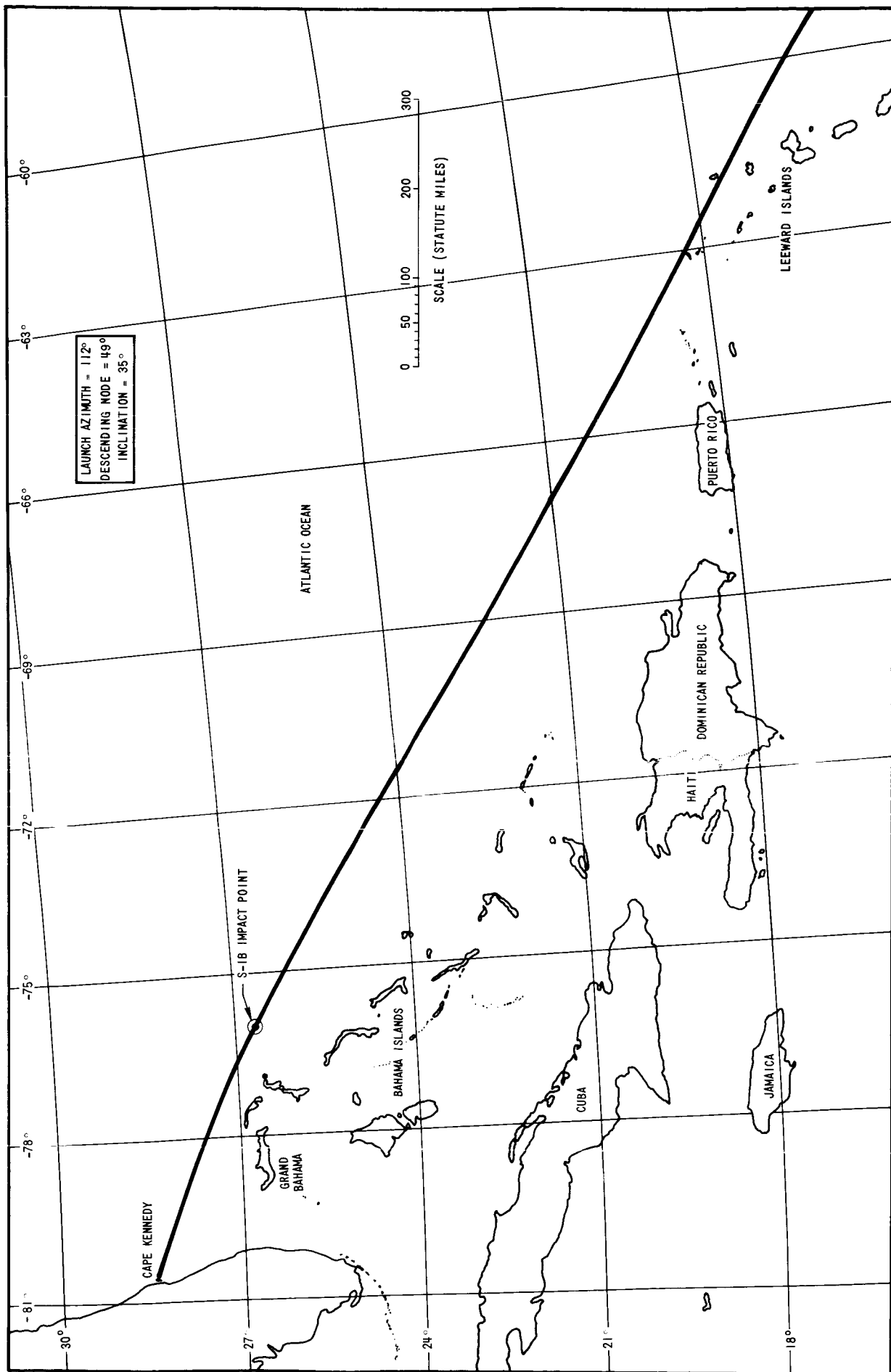


FIGURE 6 - ENLARGEMENT OF WEST INDIES PORTION OF IIP PLOT IN FIGURE 5